# Carbon Measuring / Monitoring, Reporting, Verification

*Josef Kellndorfer*
*The Woods Hole Research Center*

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# Contributors

- Richard Birdsey, USDA Forest Service
- Michael Behrenfeld, Oregon State University
- Ruth DeFries, Columbia University
- Marcia Macedo, Columbia University
- Molly Macauley, Resources for the Future
- Greg Asner, Carnegie Institute
- Anthony Freeman, JPL
- Charles Miller, JPL
- Sassan Saatchi, JPL
- Alessandro Baccini, WHRC
- Richard Houghton, WHRC
- Gillian Galford. WHRC
- Scott Goetz, WHRC
- Wayne Walker, WHRC
- Nora Greenglass, WHRC

# Outline

- Monitoring Carbon: Two View Points
- Brief History of REDD+ MRV needs in the policy context
- Examples of progress for Carbon MRV
- National and International Activities
- Outlook

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# Monitoring Carbon: Two Viewpoints

- Inform and guide policy
  - Why do we care about the C cycle?
  - Are forests and land cover change critical components in C cycling worthwhile tackling?
  - How are the fluxes spatially distributed?
  - Guide the policy framework for REDD+
    - Economic viability
    - Not all C is equal (e.g., co-benefits of ecosystem services)
- Integral part of policy implementation
  - UNFCCC Reporting requirements on National emissions (all Carbon pools)
    - REDD+ agreement with Reporting and Verification requirements
  - Voluntary Markets

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# COP-13: Bali Action Plan

- Includes Reducing Emissions from Deforestation and Degradation (REDD) as a potential option to reach climate goals; guidance on REDD demonstration activities provided
  - Second "D", degradation, is added.


# COP-14: Poznan

- "+" (POZNAN COP14) Enhancement of C Stocks, Conservation of C Stocks and Sustainable management of forests

# COP-15: Copenhagen REDD Summary

- No formal decision on REDD+

But:

- SBSTA draft decision with guidance on monitoring and measurement methodologies to establish national forest monitoring systems which uses a combination of remote sensing and ground-based forest carbon inventory approaches.

COP15
COPENHAGEN
UN CLIMATE CHANGE CONFERENCE 2009

# Cancun (COP 16) Agreements


- Officially created international REDD+ mechanism under the UNFCCC
  - Phases I and II (readiness and demonstration) made operational (funded by "fast start financing" from developed countries in Copenhagen)
  - Requests AWG-LCA to explore options for Phase III (results-based) financing
  - Request for work programs under SBSTA
    - Information systems for safeguards, RELs/RLs, forest monitoring, MRV, drivers of deforestation and degradation

# State of the SBSTA – MRV Discussion

- Forest monitoring frameworks mentioned only obliquely in SBSTA text from June, MRV more prevalent issue
- "Measuring" in the context of MRV = assessment of anthropogenic emissions and removals and changes in forest C stocks and/or forest area
- Issues identified in discussion
  - Emphasis on use of existing guidance (IPCC)
  - Consistency with MRV of NAMAs
  - MRV of finance to mirror MRV of results
  - Links to RELs/RLs and finance mechanism underscore importance of MRV
  - Simplicity and transparency
  - Concerns regarding costs of MRV
  - Scale of monitoring—temporal and spatial
    - Ability to scale up or incorporate additional land uses needed
  - MRV for REDD+ must be consistent with broader MRV frameworks

# SBSTA – Information systems

- Issues identified in discussion
  - Information systems must respect national sovereignty and be adaptable to national circumstances
  - Regularity of reporting and use of existing structures
  - Building knowledge re: existing on-the-ground experiences
- … and from latest submissions
  - How the outputs of national information systems will be reported into international processes
  - Emphasis on using National Communications and biennial update reports, tied into broader MRV processes
  - Participatory process

# SBSTA Discussion on – RELs/RLs

- Issues identified in discussion
  - Difference between RELs and RLs (no formal differentiation at this point)
  - Relationship of national to sub-national and/or regional RELs/RLs
  - Need for transparency, simplicity (lack of data, technical capacity)
- … and from latest submissions
  - Emphasis on defining the scope, purpose, and characteristics of RELs/RLs in Durban
  - Important links to MRV and compensation
  - RELs/RLs have to be based on robust historical data adjusted for national circumstances, but little further clarification on what those circumstances may include

# REDD+ MRV Strategy needs to address:

- **Leakage**
  - MRV needs: National wall-to-wall monitoring of changes in LU/LC to guard against leakage.
- **Permanence**
  - MRV needs: Continuous time-series and spatially consistent monitoring to maximize permanence.
- **Baselines**
  - MRV needs: Time-series consistent monitoring to determine historical emissions in spatially-explicit manner.
- **Additionality**
  - MRV needs: National wall-to-wall monitoring + baseline information.

# SBSTA Expert Groups Recurring Topics:

- *Gaps in data, information and tools*
  - *Estimates of standing stocks per hectare;*
  - *Estimates of carbon stocks and emissions from the below-ground biomass pool;*
  - *Estimates of biomass density, development of biomass expansion factors and allometric equations;*
  - *Improved estimates at the levels of forest type and forest ecosystem;*
  - Estimates of potential emissions from forest fires
  - More socio-economic data that could be used to improve modelling of reference emission levels.
- Need for Country Capacity Building on use of Data and Tools

http://unfccc.int/resource/docs/2009/sbsta/eng/02.pdf

# Governors' Climate and Forests Task Force (GCF)


## What is the GCF?

A unique multijurisdictional collaborative effort between 15 states and provinces focused on the development of rules and capabilities necessary to generate compliance-grade assets from REDD.

# Governors' Climate and Forests Task Force (GCF)

## Why does the GCF matter?

- The GCF states and provinces encompass more than 20% of the world's tropical forests
- The GCF includes key U.S. states that are at the leading edge of subnational compliance systems in the U.S. including California
- The GCF represents the first attempt at any level of governance to move into the "proof-of-concept" stage in an effort to bring REDD into existing and emerging GHG compliance systems and markets
- The GCF is developing concrete recommendations for policy makers and regulatory authorities for incorporating REDD into emerging GHG compliance systems
- The GCF is now the focal point globally for bringing sub-national REDD efforts into ongoing national and international policy discussions and developments

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# Selected Activities Relevant to MRV

- many excellent activities within NACP, LBA and other NASA programs …
- Please pardon being selective to illustrate some points related to progress in MRV

# The Roles of Verification or Reference Sites in MRV Systems

- Validation sites for carbon stock and flux estimates from remote sensing and models
- Data for:
  - Estimates of ecosystem C pools
  - Parameters of process models
  - "Emission factors" for reporting
- Coordination and consistency for MRV among countries with different circumstances

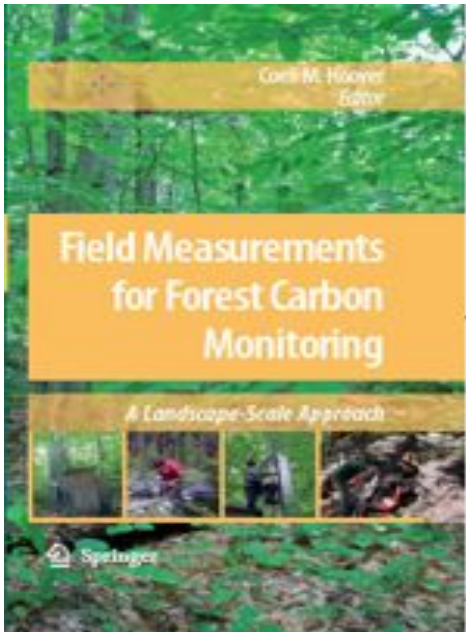
Courtesy Birdsey et al.

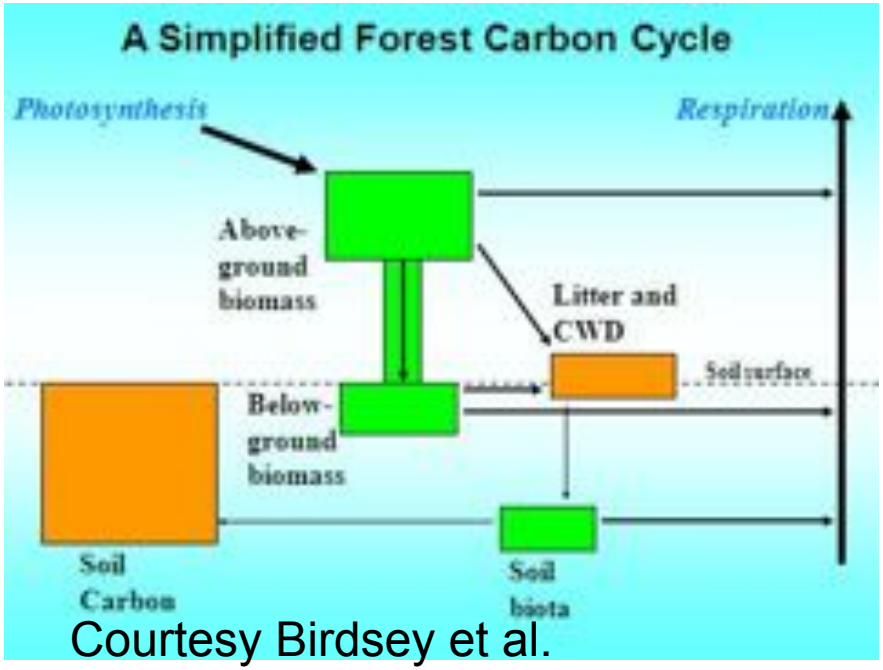

**Validation sites for NASA-CMS Pilot Project**

**Expanding network to Central and South America**

# Basic Measurements at MRV Verification or Reference Sites

- **Biometrics** – repeated measurements of ecosystem C pools
- **Eddy flux towers** – monitoring of C exchange between land and atmosphere
- **Remote sensing** – high-resolution vegetation structure, composition, and change



Courtesy Birdsey et al.

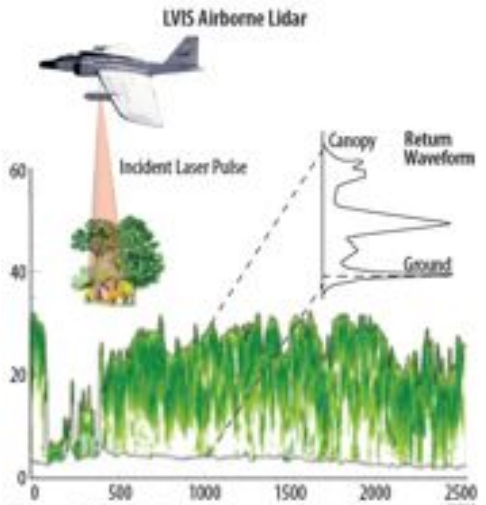


**Figure 1-3:** The Laser Vegetation Imaging Sensor or LVIS instrument is a GSFC scanning full waveform retrieval system that has been extensively used over a variety of targets including Greenland, Arctic sea ice, Antarctica, forest locations in the US, Costa Rica, and elsewhere.

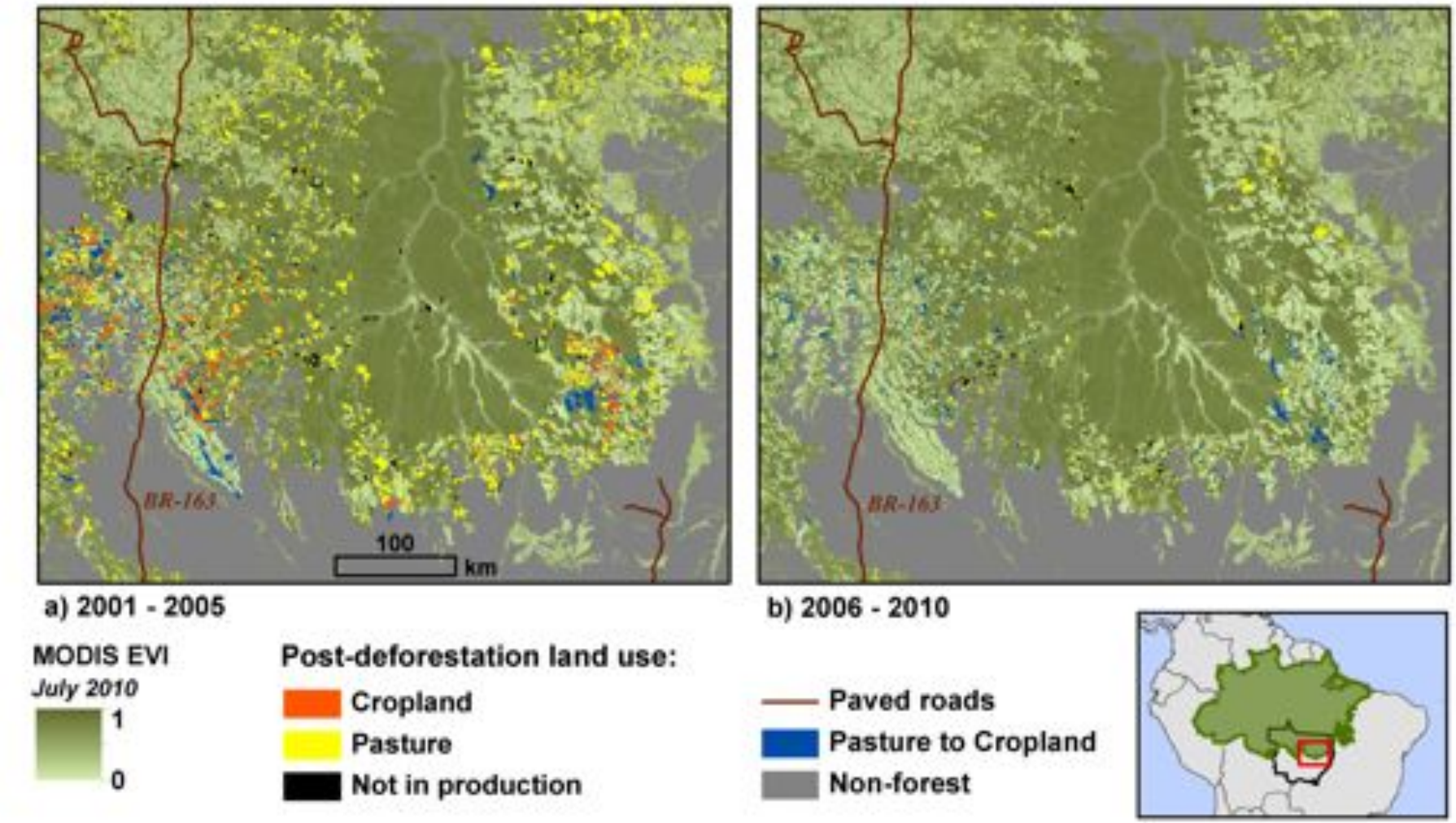
# Selected MRV Variables and Measurement Methods

Scaling up ←

| Variable | Remote Sensing | Forest Inventory | Intensive Sites |
|---|---|---|---|
| Land cover | X | X | X |
| Leaf area | X | X | X |
| Disturbance | X | X | X |
| Stand structure | X | X | X |
| Live biomass | | X | X |
| Species composition | | X | X |
| Growth, removals, mortality | | X | X |
| Litter fall | | | X |
| Soil $CO_2$ flux | | | X |
| Dissolved Organic C | | | X |
| Net Ecosystem Exchange of $CO_2$ | | | X |

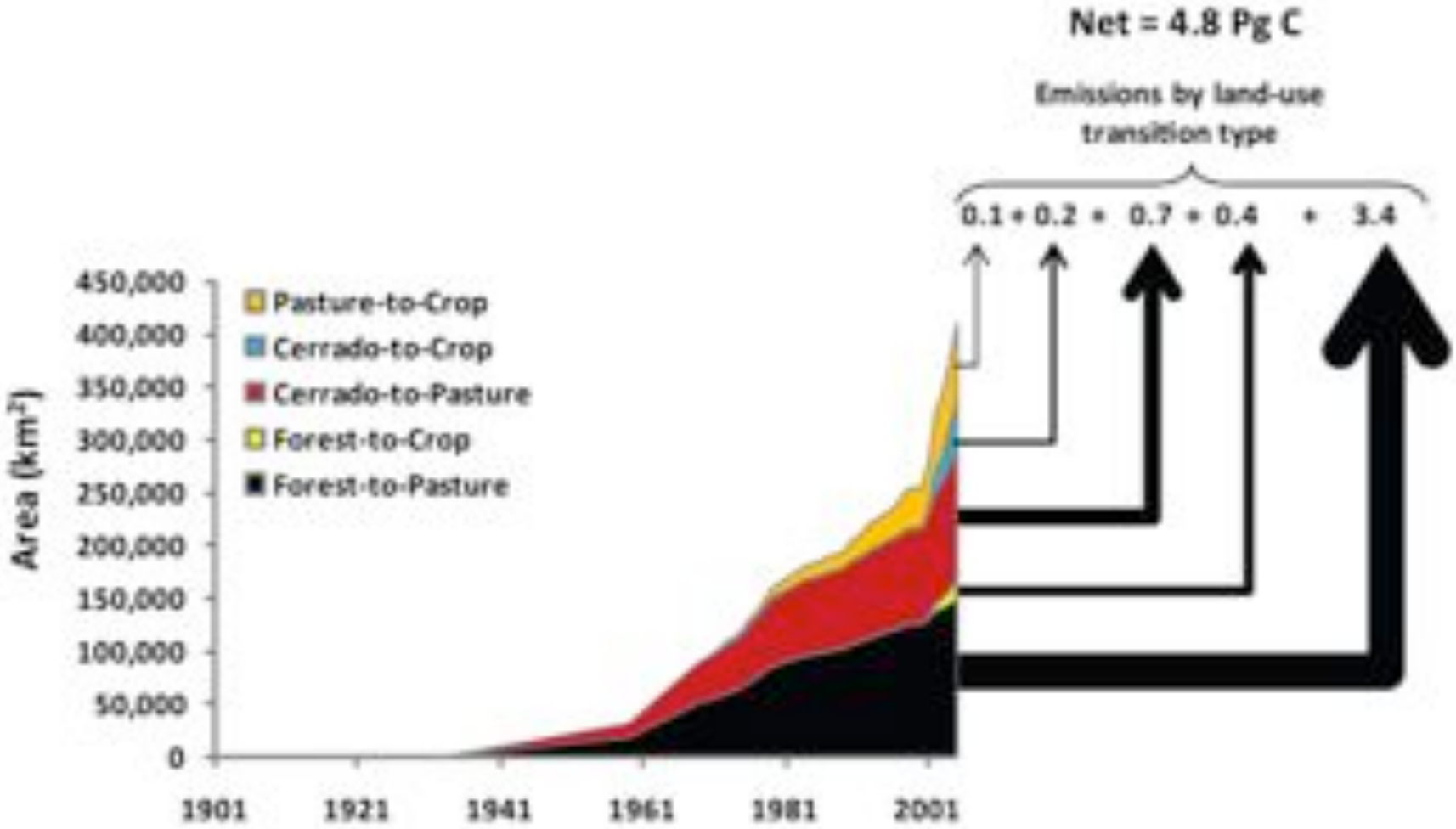
Courtesy Birdsey et al.

# Tracking land use transitions with MODIS




Macedo et al. 2011, *In Review*

# Emissions by land use transition




Galford et al. 2011, *Ecol. App.*

# Carbon Monitoring Study-Biomass Pilot Project

**GOAL:** Provide geospatially explicit, consistent estimates of aboveground terrestrial vegetation biomass and carbon storage for the U.S. by combining advanced satellite products with ground observations and to evaluate the nation's need for monitoring carbon storage.

**RESULTS:**

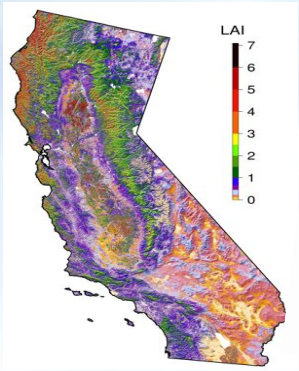
**1. A National Carbon Calculator** has been developed and is under evaluation in California and northeastern states.

**2.** Analysis of USDA forest inventory data (FIA) over California indicate that a combination of L-band radar backscatter, forest height derived from SRTM and ground elevation explains greater than 60% of the variability of vegetation biomass.

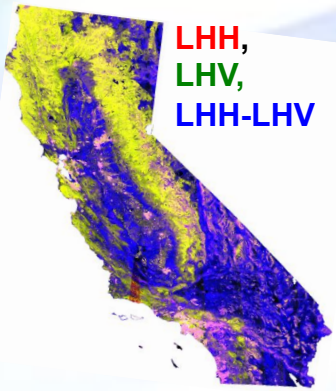
**3**. Largest source of uncertainty in regional estimates of forest carbon is sampling density of ground or lidar measurements of forest structure.

**4.** First carbon storage map of the US produced by using ICESAT GLAS lidar, MODIS, QSCAT, SRTM data at 1km.

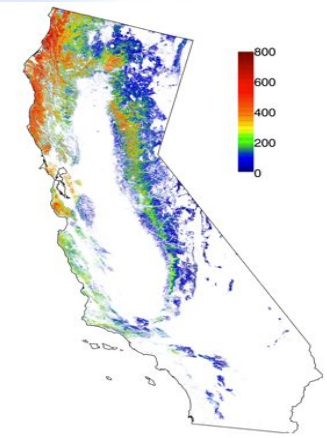
NASA/ARC MODIS LAI



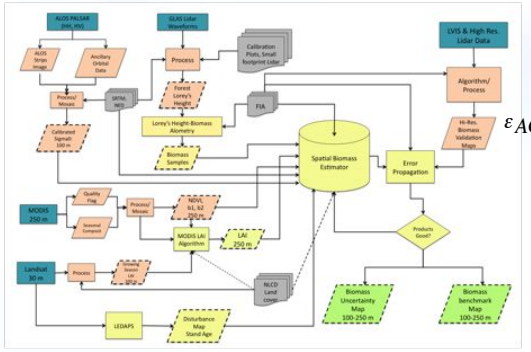

ALOS L-band Mosiac




California Forest Carbon Stock



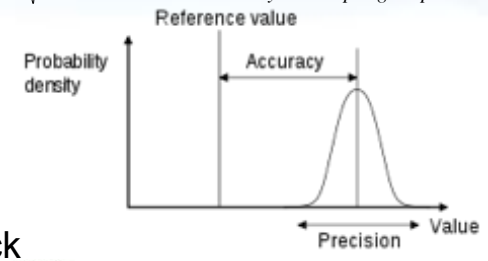

CMS-National Carbon Calculator



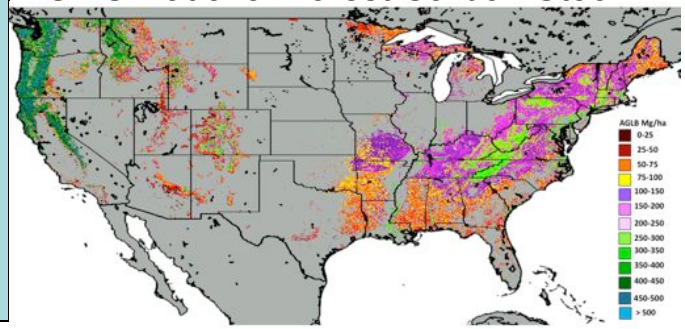
\+

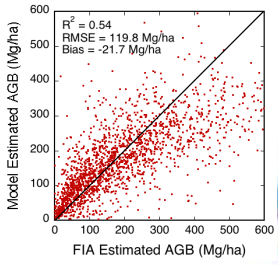
Pixel-level Uncertainty

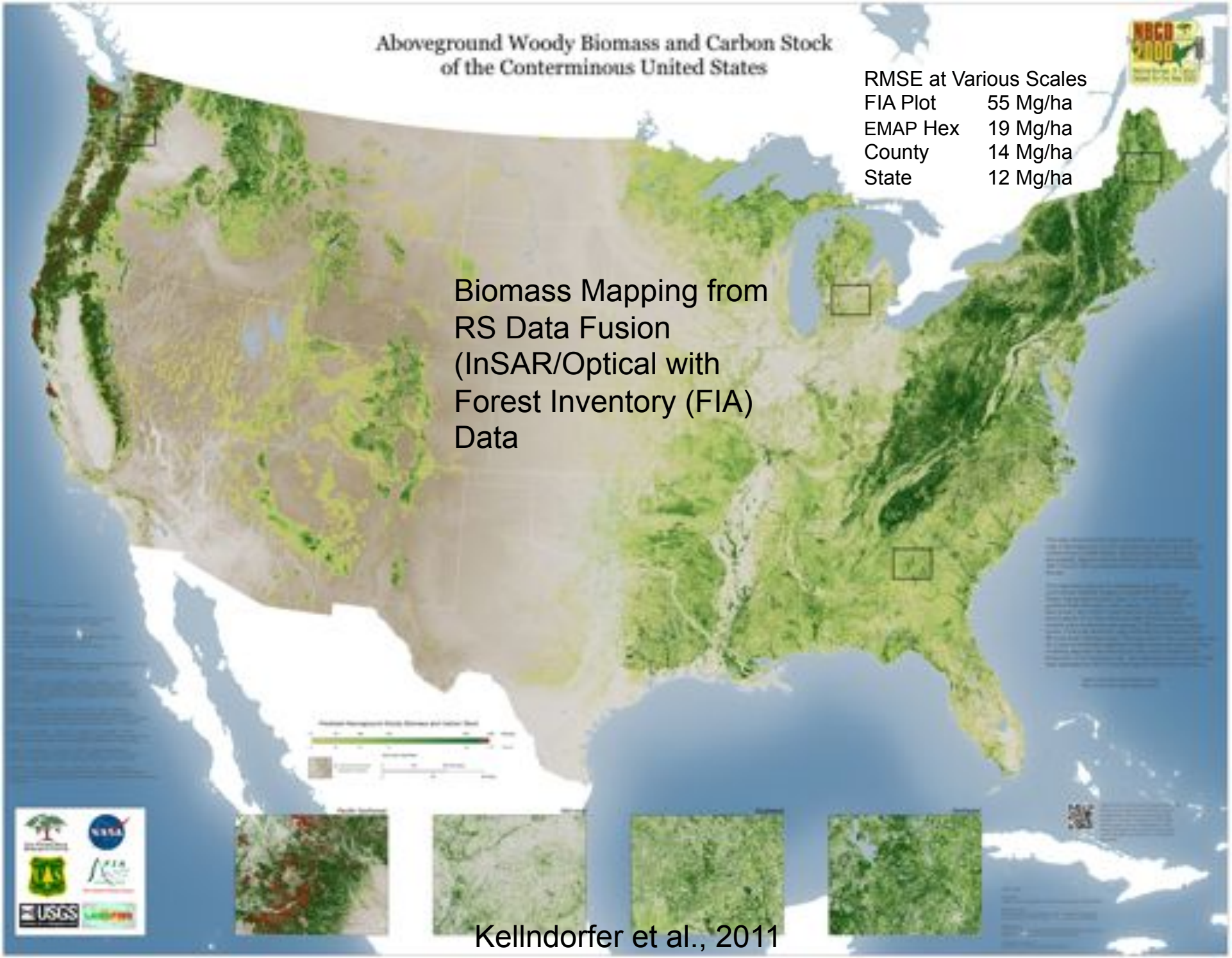
$$\varepsilon_{AGB} = \sqrt{\varepsilon^2_{measurement} + \varepsilon^2_{allometry} + \varepsilon^2_{sampling} + \varepsilon^2_{prediction}}$$




CMS National Forest Carbon Stock




Aboveground Woody Biomass and Carbon Stock
of the Conterminous United States
RMSE at Various Scales
FIA Plot 55 Mg/ha
EMAP Hex 19 Mg/ha
County 14 Mg/ha
State 12 Mg/ha
Biomass Mapping from RS Data Fusion (InSAR/Optical with Forest Inventory (FIA) Data
USGS
Kellndorfer et al., 2011

# A Benchmark Map of Carbon Storage in Tropics
## Saatchi et al. PNAS 2011

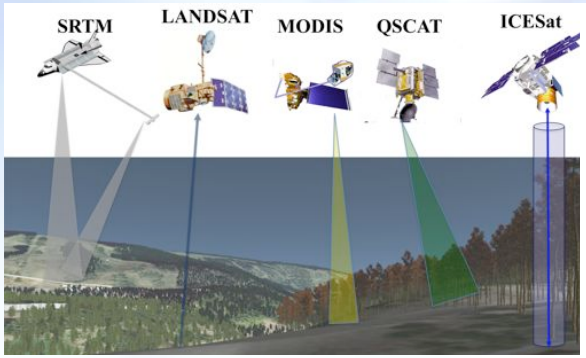
Different NASA satellites including more than 3 million ICESAT GLAS Lidar measurements of forest height are used to create the most precise map depicting where -- and how much -- carbon is stored in Earth's tropical forests. The high-resolution map is expected to provide a baseline for ongoing carbon monitoring and research, and serve as a useful resource for managing the greenhouse gas carbon dioxide.

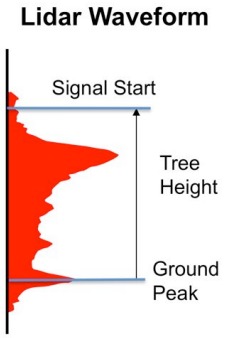
**Highlights:**

**1.** The map shows that in the early 2000s, forests in the 75 tropical countries studied contained 247 billion tons of carbon or an equivalent of 900 billion tons of carbon dioxide. For perspective, about 35 billion tons of carbon dioxide is released to the atmosphere annually as a result of human activities.

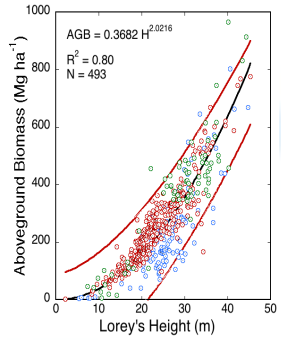
**2.** Forests in Latin America hold 49 percent of the carbon in tropical forests. For example, Brazil's carbon stock alone, at 61 billion tons, almost equals all of the carbon stock in sub-Saharan Africa, at 62 billion tons.

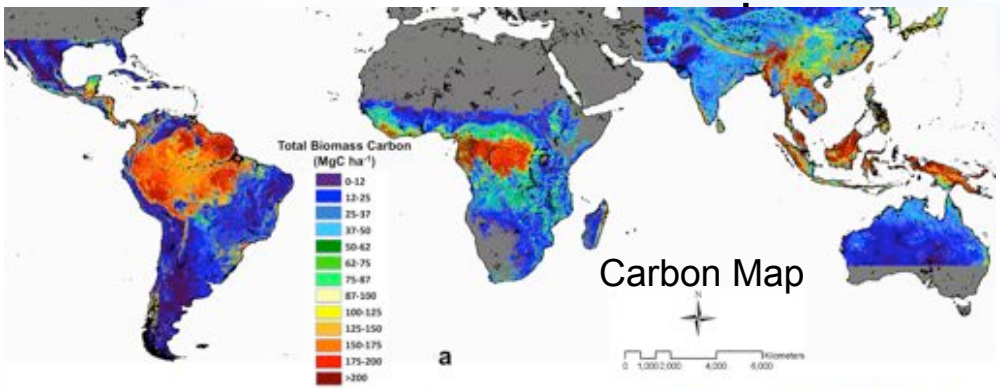
A Satellite and in situ Observations integrated in spatial carbon estimator

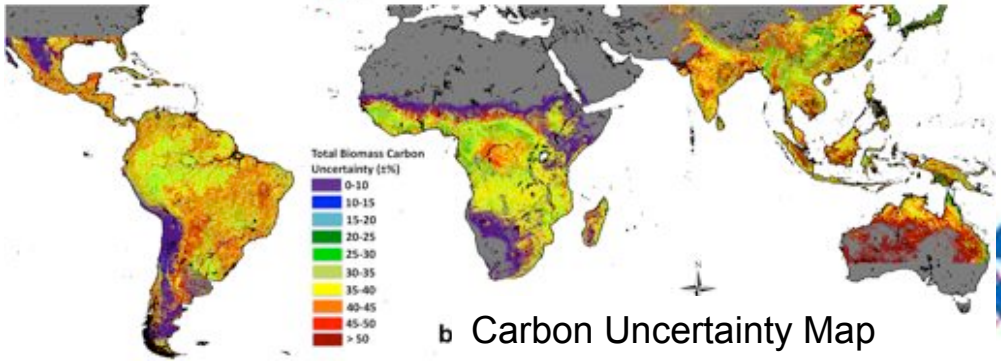


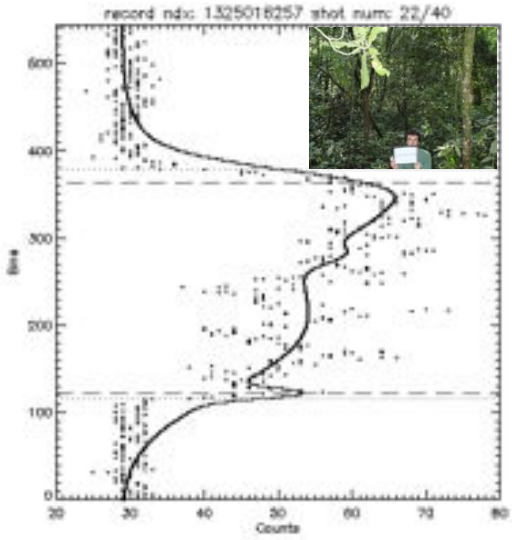

More than 3 million Lidar Shots converted to forest biomass



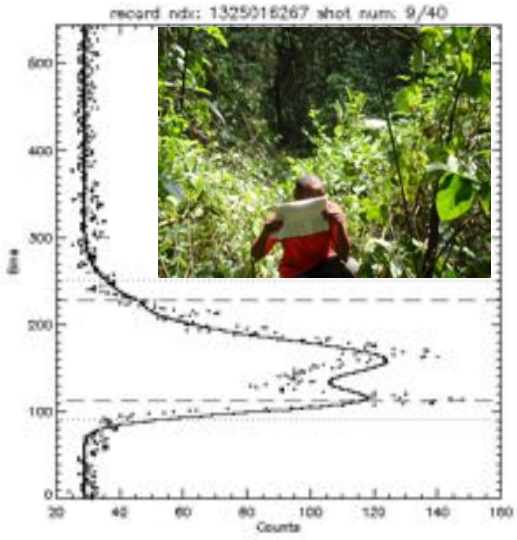



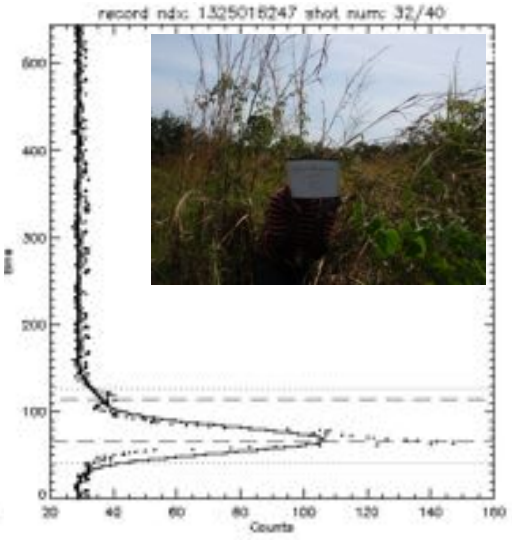
# Co-located Field Measurements



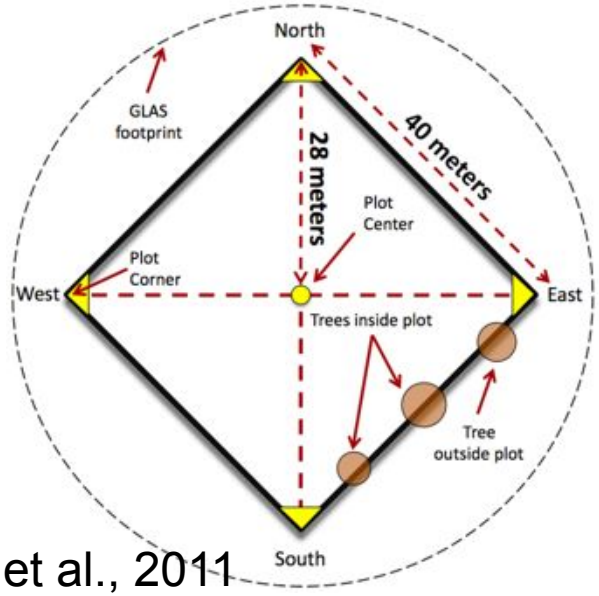

Biomass = 205 (t/ha)




Biomass = 78 (t/ha)



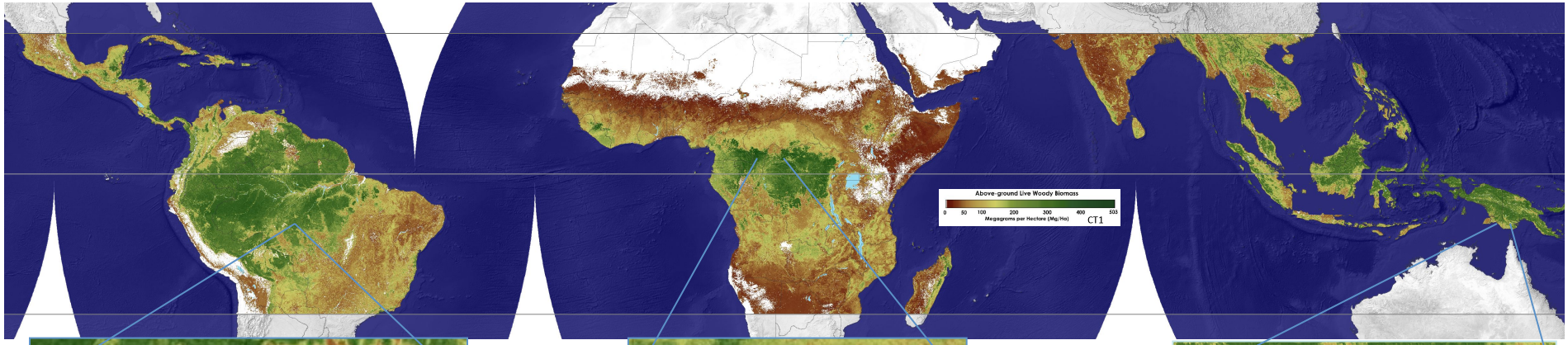

Biomass = 30 (t/ha)

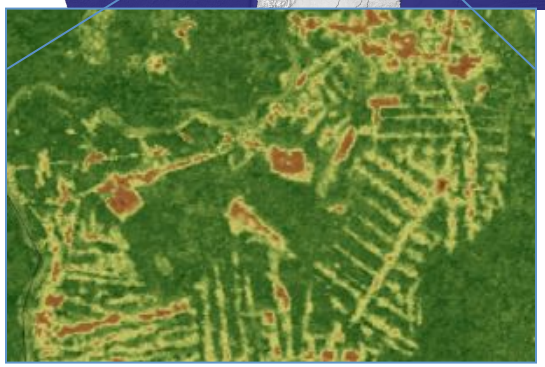



Baccini et al., 2011

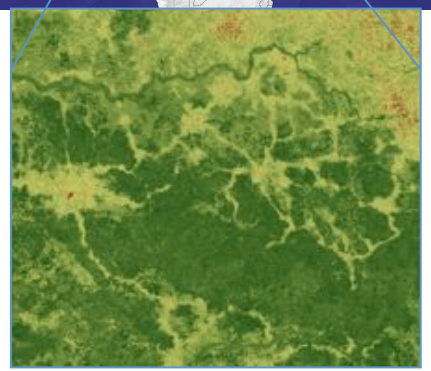
# Pantropical Forest Carbon Mapped with Satellite and Field Observations

(500m resolution)

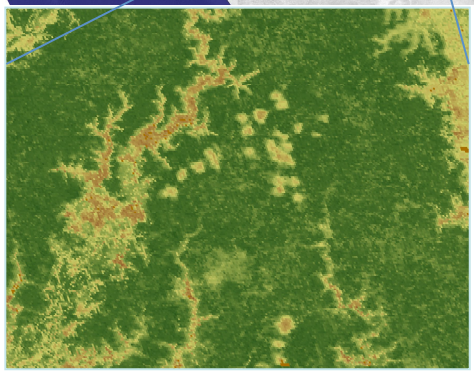


Amazon Basin detail
(accuracy 25 Mg C $ha^{-1}$)



Congo Basin detail
(accuracy 19 Mg C $ha^{-1}$)



Papua New Guinea detail
(accuracy 24 Mg C $ha^{-1}$)

Baccini et al., 2011

# Forest Carbon in the Peruvian Amazon Pilot Study 2009

4.3 million ha
(10.8 million acres)

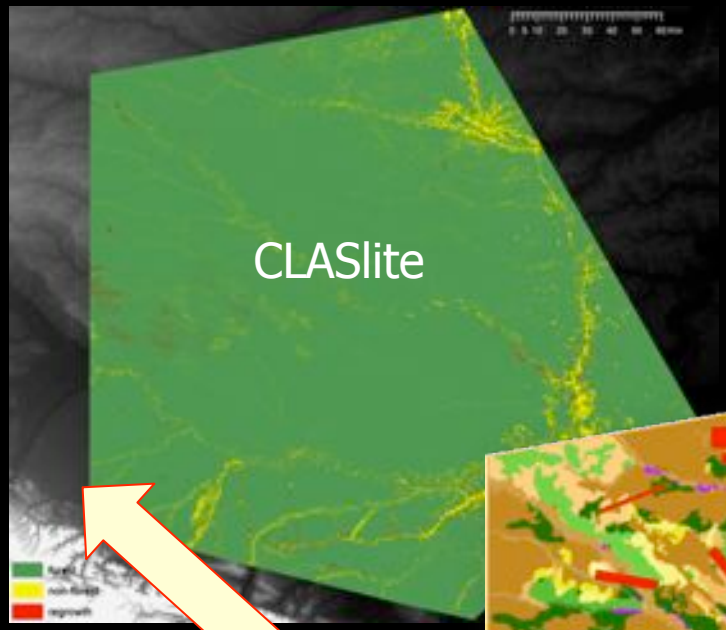
This demonstration area is the size of all of Panama's forests, or

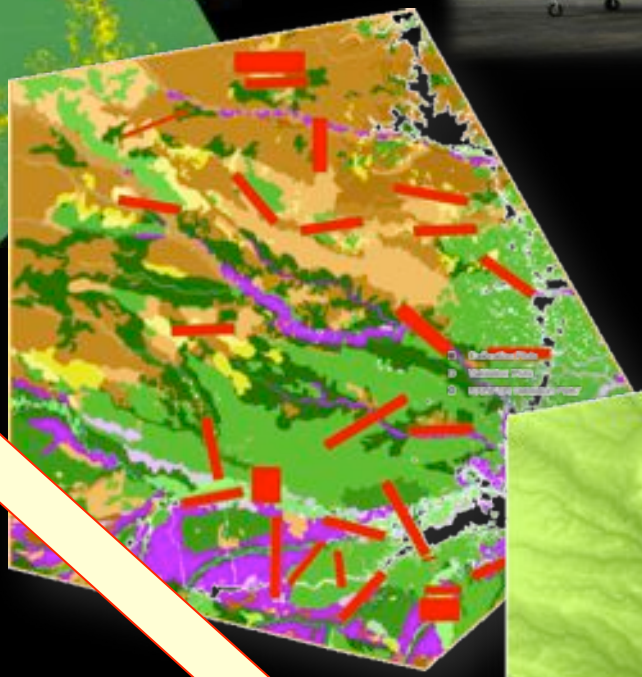
2 times the size of Costa Rica's forests, or

the size of Denmark.


Courtesy G.Asner

# Carnegie REDDlite Methodology




Courtesy G.Asner

# LiDAR
# "Light Detection and Ranging"

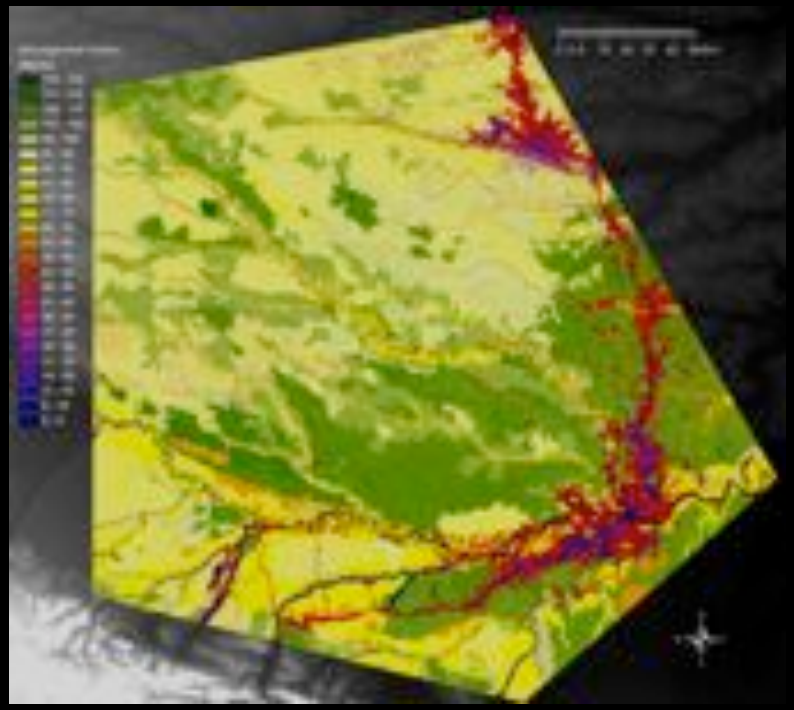

Forest clearing

Secondary forest

Forest degradation

Courtesy G.Asner

High-resolution C basemap *adjusted by* Continuous CLASlite satellite monitoring



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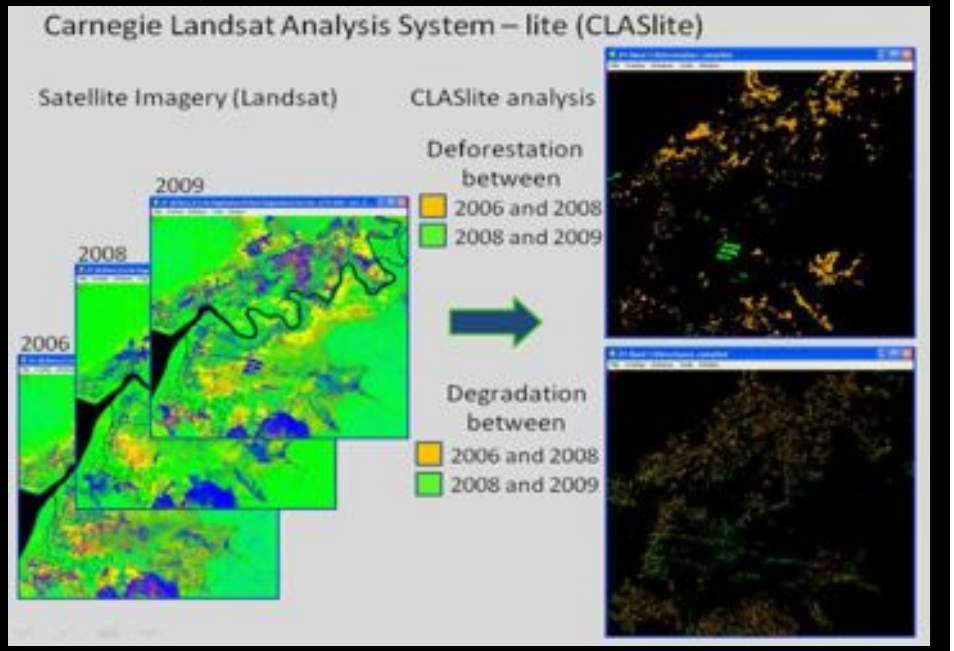
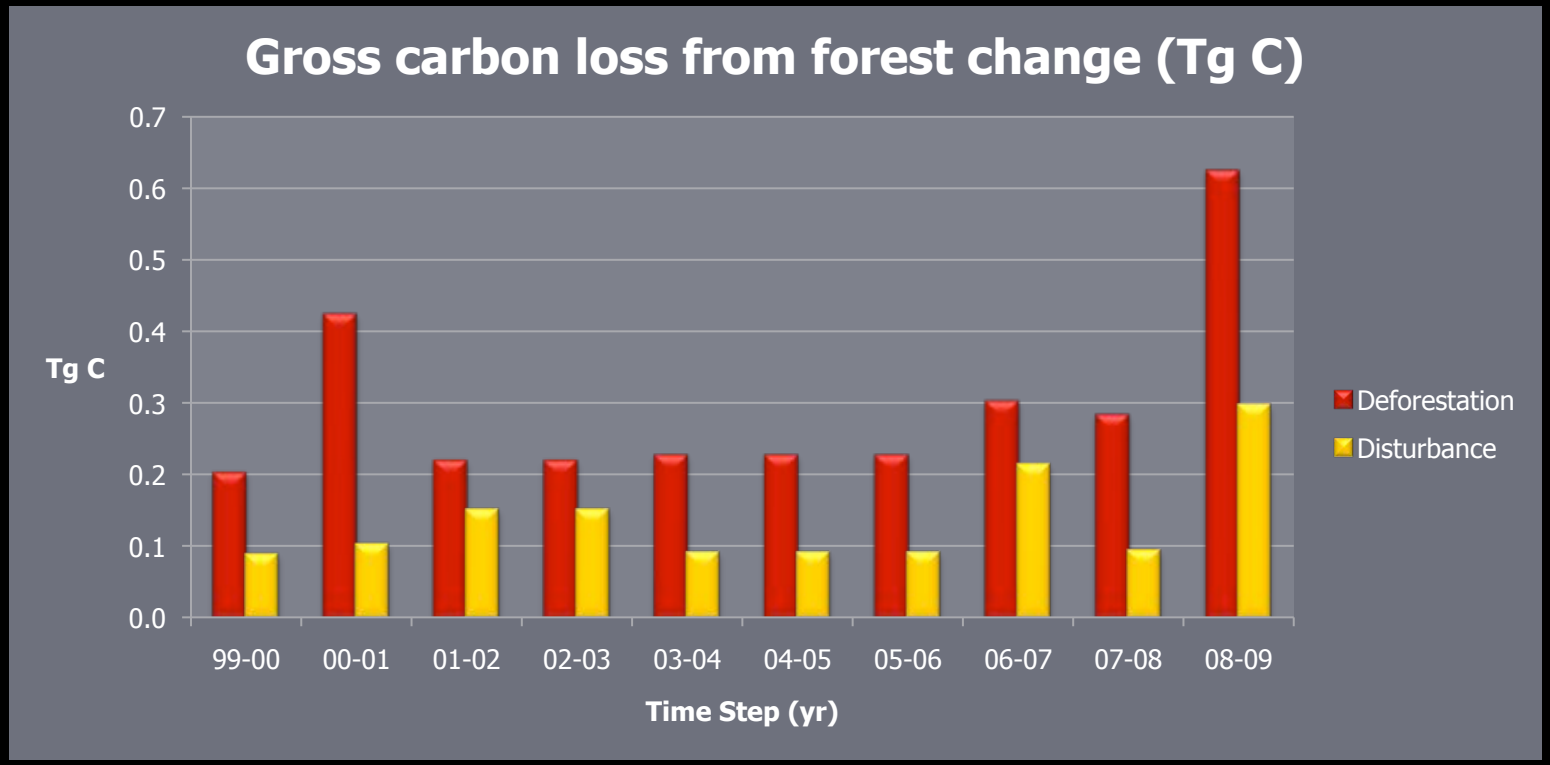



Carbon Emissions

Courtesy G.Asner

# Gross Carbon Emissions from REDDlite

THIS IS WHAT IS REQUIRED FOR DECISION-MAKING




- **1 Tg = 1 million metric tons**
- **Carbon emissions from forest disturbance average 47% of deforestation.**

Courtesy G.Asner

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# Some REDD+ MRV related Activities and Groups

- GOFC-GOLD: REDD Sourcebook
- GEO
  - Forest Carbon Tracking Task (National Demonstrators)
  - Global Forest Observing Initiative (GFOI)
- U.S. SilvaCarbon
  - Network of Experts
- NASA Carbon Monitoring System Pilots
- Verified (former Voluntary) Carbon Standard (VCS) group

GROUP ON EARTH OBSERVATIONS | Forest Carbon Tracking

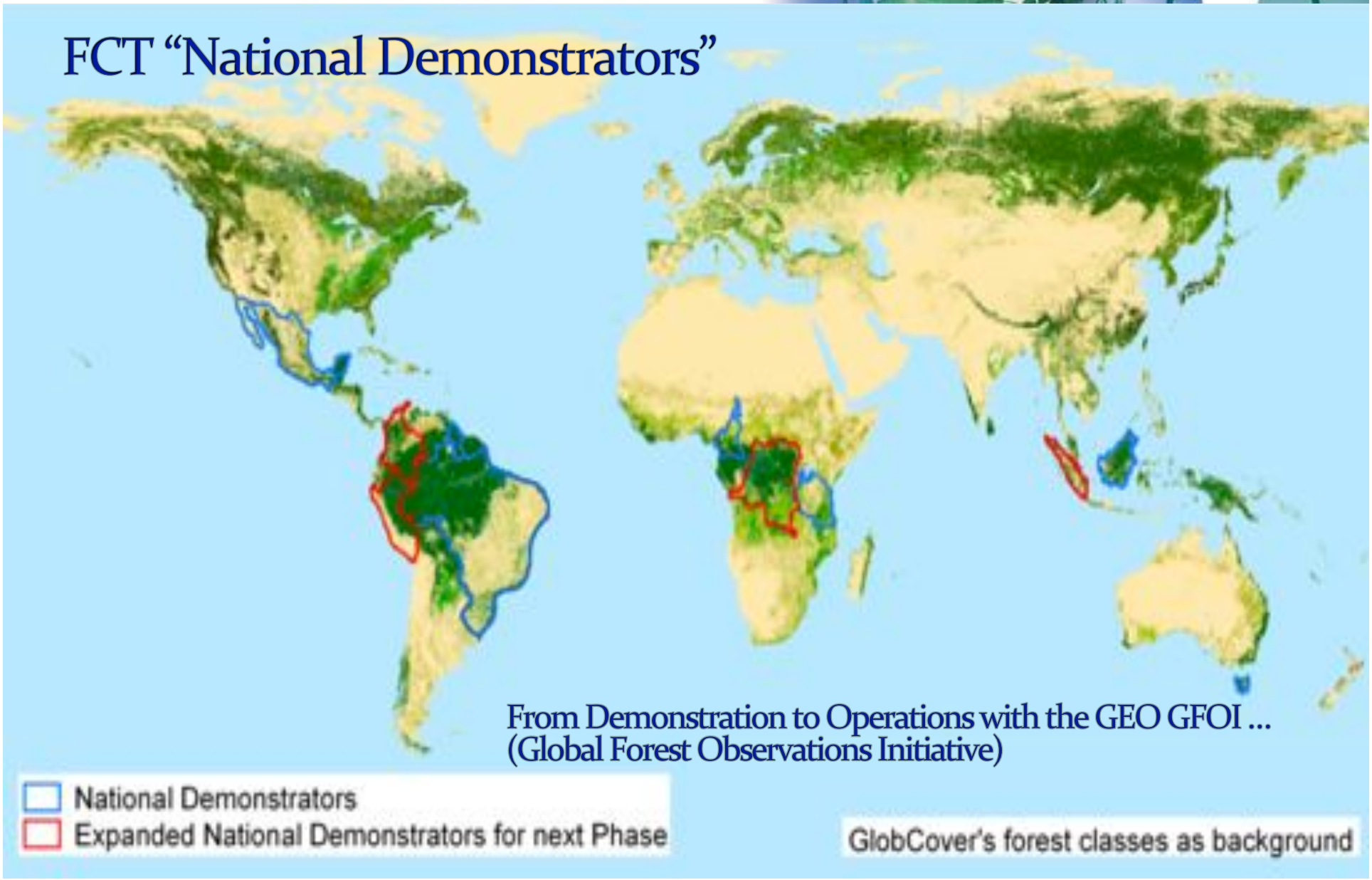
- *Define a set of standards, methods and requirements that future spatially explicit National Forest Monitoring and Carbon Accounting Systems could adopt*
- *Coordinate the use of data from current and planned Earth observing satellites operated by GEO member countries to provide the technical capability and continuity to MRV*
- *Coordinate the use of in-situ data, models and verification techniques*
- *Secure time-series of SAR and optical satellite data and analysis tools, integrated with ecosystem models and in-situ data, that can be used interoperably and in complementary for MRV.*
- *Appropriate international institutional frameworks, and supporting data policies allowing open access and application of the supporting satellite datasets will be essential to secure the sustained supply of information in support of MRV requirements.*

The Forest Carbon Tracking task is organized under the GEO 2009-2011 task plan CL-09-03b
Complements other GEO Tasks related to Forests and Biodiversity Assessment
http://www.geo-fct.org

GROUP ON EARTH OBSERVATIONS | Forest Carbon Tracking

CEOS Committee on Earth Observation Satellites

# FCT "National Demonstrators"



# SilvaCarbon

**U.S. science, innovation and technical expertise to assist developing countries in monitoring and managing forest and terrestrial carbon**

*Announced by OSTP at GEO Summit in Bejing, Nov. 2010*

*Objective 1: Demonstrate and compare forest and terrestrial carbon measurement and monitoring methodologies.*

*Objective 2: Build capacity of selected developing countries to use forest and terrestrial carbon monitoring and management methodologies and technologies.*

*Objective 3: Facilitate, in cooperation with the Committee on Earth Observing Satellites (CEOS) and other partners in the GEO Forest Carbon Tracking task, the coordinated collection and dissemination of earth observation data related to forest and terrestrial carbon monitoring and management.*

*Objective 4: Strengthen the community of forest and terrestrial carbon technical experts*

http://www.usaid.gov/climatechangeweek/docs/silvacarbon_factsheet.pdf

# Outline

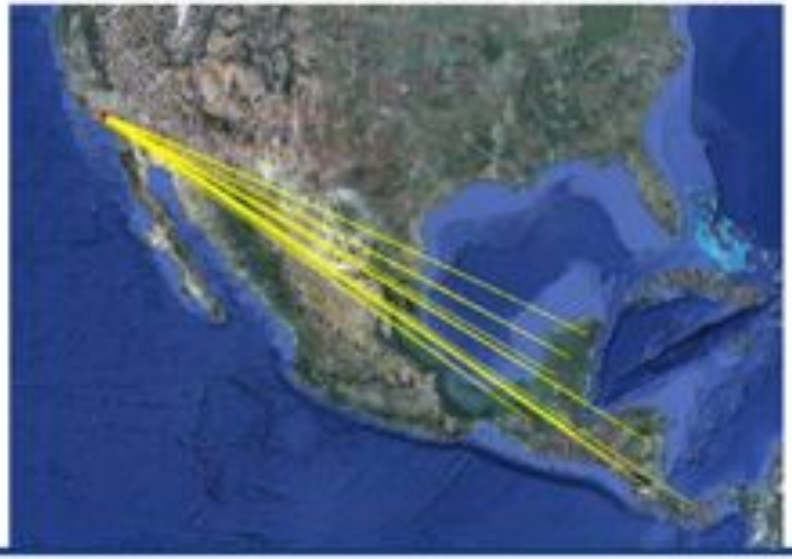
- Monitoring Carbon: Two View Points
- Brief History of REDD+ MRV needs in the policy context
- Examples of progress for Carbon MRV
- National and International Activities
- Outlook

# REDD Validation using Airborne Remote Sensing?

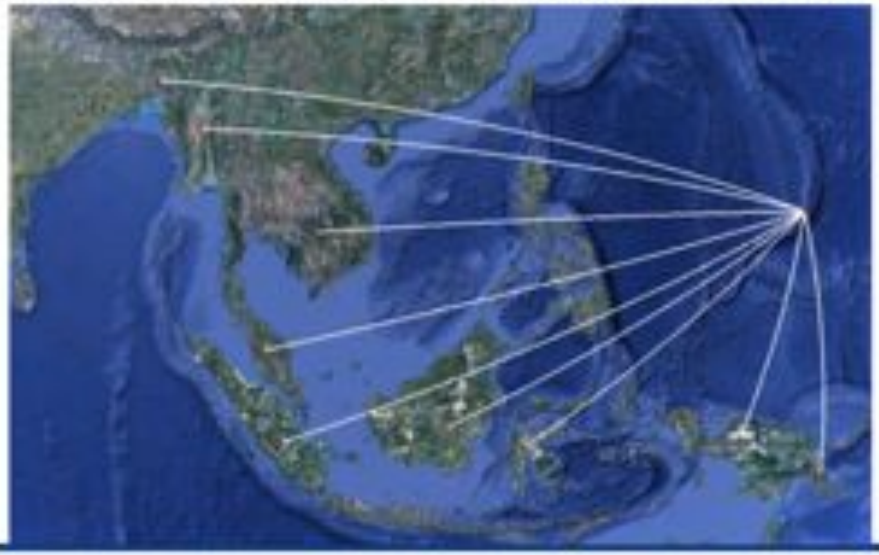
According to Hansen et al, PNAS, 2010, 3.1% of global forests are subject to deforestation or fire every five years.

Campaign analysis shows it is feasible to observe 5% of the world's tropical forest area per year using a dedicated RQ-4A GlobalHawk with conservative mass and fuel margins.

**Candidate Sorties from Dryden**



**Candidate Sorties from Andersen AFB**



Source: T. Freeman

# Phytoplankton Carbon, Physiology, and Productivity

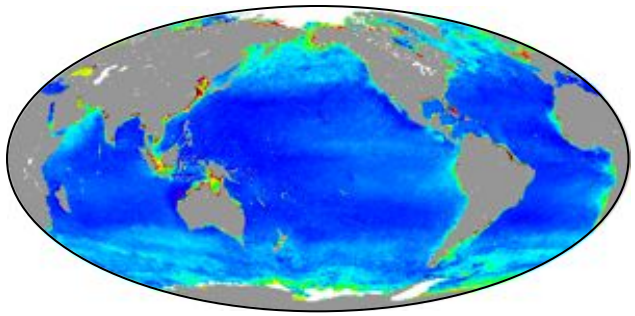
**What?** NASA funded research is now providing new global fields of phytoplankton carbon stocks and new field approaches for validating these carbon products.

**Significance:** The validated carbon products allow tracking of regional changes in a key ecosystem property and, when combined with simultaneous retrievals of chlorophyll, improved assessments of change in ecosystem physiology and productivity.

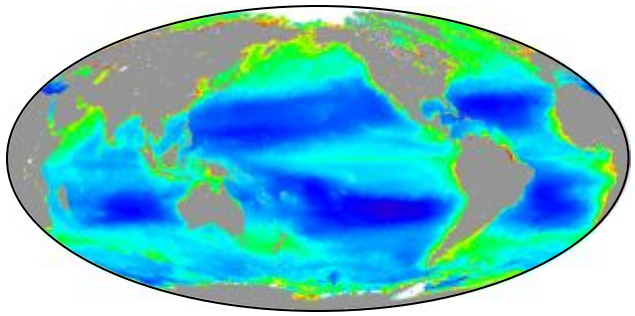
**Future:** Advanced ocean color sensors, such as envisioned for the ACE mission, will expand the spectral measurement range into the ultraviolet and provide higher spectral resolution to address current uncertainties in ocean ecosystem retrievals to yield more accurate assessments of phytoplankton biomass and productivity

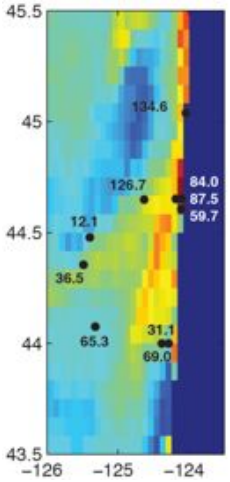
Courtesy M. Behrenfeld

Carbon



Chlorophyll



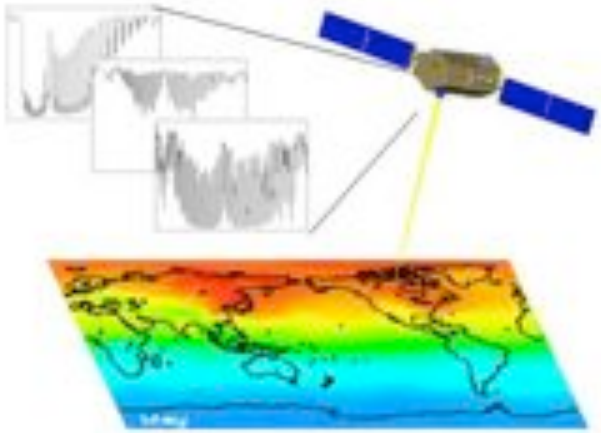



**Validation**

New technologies are now emerging that allow routine measurement of phytoplankton biomass for the first evaluation/ validation of satellite products

# Monitoring $CO_2$ Sources

- The main objectives of the OCO Mission are to identify regional scale natural $CO_2$ sinks and monitor their variability over the seasonal cycle
- To characterize sinks, which are weak and spatially extensive, the Observatory must also be able to detect and characterize $CO_2$ *sources*
- Compared to sinks, *sources* are
  - much stronger
  - more localized
  - more variable



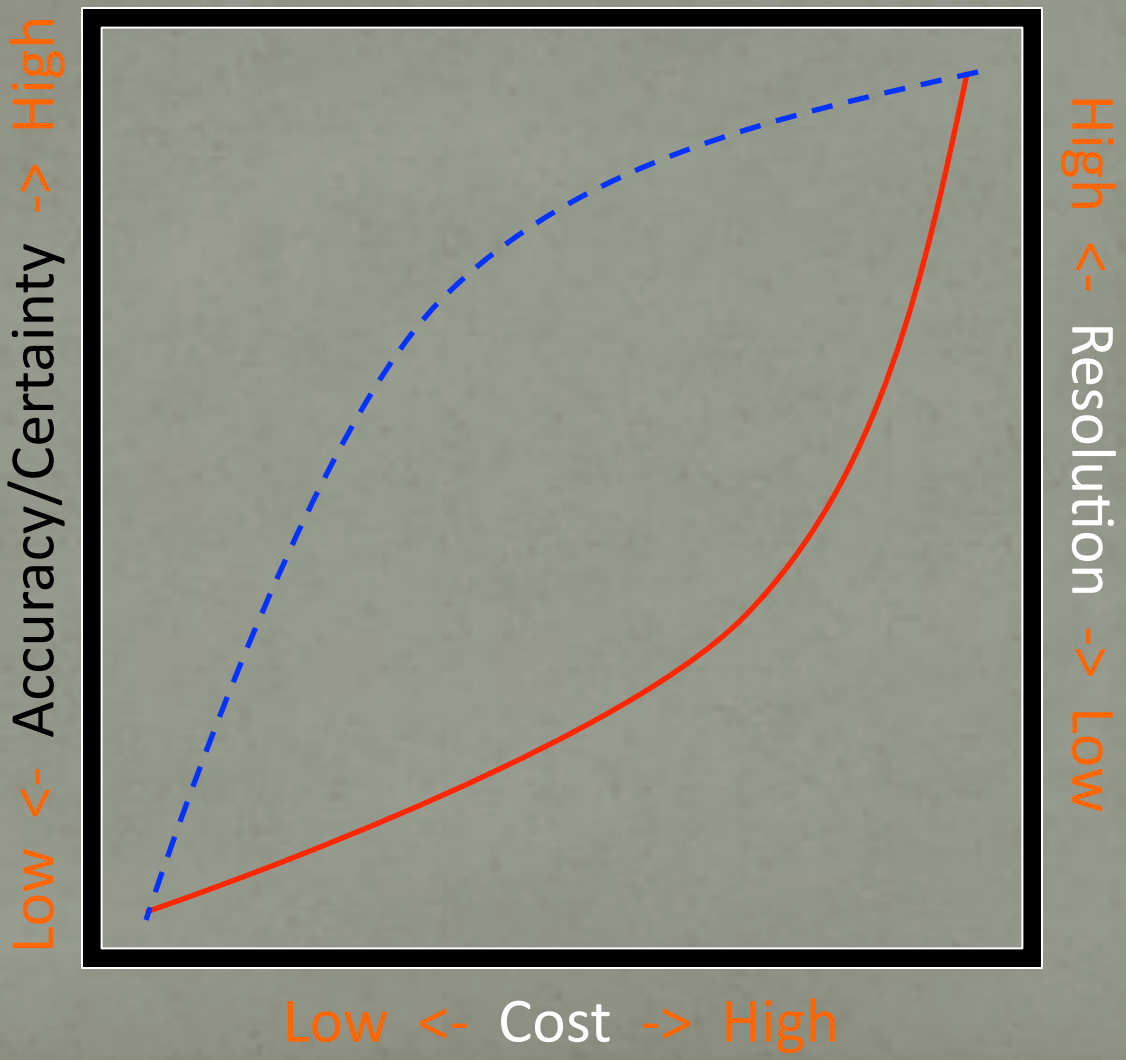
Courtesy C. Miller

# OCO Travels Over California 6 Times Every 16 Days

- The green lines represent OCO flight paths over California and neighboring land and ocean regions
- 6 flight paths sample large portions of California
  - Numbers are not in order of actual occurrence
- These flight paths are repeated every 16 days
  - ~2 weeks between exact revisits
  - 5 days between nearest neighbor paths
- OCO makes more than 20,000 measurements over California every month
  - Clouds and aerosols will prevent many measurements from sampling all the way to the surface
- Measurements from flight paths over the land and ocean regions surrounding California can establish the net flow of $CO_2$ emissions in and out of the state


Courtesy C. Miller

# MRV transaction cost consideration




NASA's contribution to C monitoring with sensors, science, and capacity building

# Vision for NASA's Role in C-MRV

- Continued development and deployment of sensors (spaceborne and airborne) with sensitivity to vegetation 3D structure (Lidar/radar), atmospheric and ocean carbon pools
- Foster consistency of relevant data sets and methods
- Provide open data access to maximize participation of Nations in good practice MRV
- Lead the science to improve the methods and reduce the uncertainty in multi-scale products
- Guidance on Map comparison: VALIDATION!
- Foster Field-Airborne-Spaceborne nested approach to C monitoring
- Science Communication to Policy Makers (explain models and uncertainty)
- Engage in Capacity Building!